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FINAL REPORT

EVALUATION OF SYSTEM VARIABLES IN STAGE II REFUELING OPERATIONS

By

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Prepared for:

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Emission Testing Branch
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This report covers the statistical analysis of the variables affecting hydrocarbon emissions during Stage II refueling operations for vapor balance recovery systems done by the staff of Research Triangle Institute, Research Triangle Park, NC. The purpose of the analysis was to assist the Environmental Protection Agency (EPA) in developing compliance test procedures for vapor balance recovery systems at service stations. In particular, the analysis was performed in order to determine the number of vehicles needed to establish a baseline curve for the system and to estimate and test, statistically, the significance of the estimated vapor emission rate.

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1.0 Introduction

Under Task Order 14, Contract No. 68-02-0607, staff of the Research Triangle Institute (RTI), Research Triangle Park, N. C., have conducted a statistical analysis of the variables affecting hydrocarbon emissions during Stage II refueling operations for vapor balance recovery systems.

The purpose of the analysis was to assist the Environmental Protection Agency (EPA) in developing compliance test procedures for vapor balance recovery systems at service stations. In particular, the analysis was performed in order to determine the number of vehicles needed to establish a baseline curve for the system and to estimate and test, statistically, the significance of the estimated vapor emission rate.

The data analyzed and upon which the vehicle numbers are based were collected by EPA by TRW, Inc., Redondo Beach, California under Contract No. 68-02-0235 [1].

2.0 General Discussion of Emission Rate

In this report, emission rate is defined as a comparison of a mean vapor recovery rate (gm/gal) of a population of cars against a potential emission rate. Specifically, if one knew, precisely, the vapor recovery for all cars in the population for which the particular standard applied, then the population mean value could be compared against the mean of the potential emissions in order to determine if the system complied with federal regulations.

As an example, suppose the mean potential emissions were given as M_B and the mean vapor recovered for all the cars in the population to which the standard applied was M_T. Then, one would make a decision with respect to the emission rate by the following:

(2.a) If $M_B - M_T > d_o$, then the system is not in compliance; d_o is a given, fixed number.

In what follows, (2.a) is called vapor emission rate (DE) and d_o is taken to be 0.4 gm/gal.

Now, the above rule is simple and straight forward; however, it cannot be implemented. Specifically, neither M_B nor M_T is known or specified; hence because M_T is not known and because M_B is not specified but is defined in terms of potential emissions, a procedure must be formulated which allows:

(2.b) The estimation of the potential emissions,

(2.c) The estimation of the mean recovery M_T,

and,

(2.d) The performance of a statistical test to determine if the difference between M_B and M_T exceeds .4 gm/gal.

3.0 Statistical Aspects of Emission Rate Determination

From the balanced vapor recovery system data collected by TRW, Inc. [1], two sets of cars were formed. The first set, consisting of 14 cars and denoted as BASE, was used to establish the standard (potential emissions). BASE cars satisfied the following criteria:

(3.a) Tank vent line blocked with a pressure gauge,

(3.b) Zero explosimeter reading during fill,

(3.c) No leaks in vehicle tank during check after fill.

The second set of cars (TEST) were vehicles which were not BASE cars and satisfied the following:

(3.d) No pressure gauge used on tank vent line,

(3.e) No force fitting or hand holding during fills.

Statistical analysis of the data (section 7.0 of this report) showed that the gm/gal recovery for the BASE cars had a decreasing linear relationship with temperature differential (vehicle tank - dispensed liquid temperature) and the TEST cars were relatively uninfluenced by temperature differential.

Hence, for the development of a procedure for assessing emission rate the following assumptions are made:

(3.f) gm/gal recovery for automobiles from which potential emissions, M_B, are to be estimated exhibit a decreasing linear relationship with temperature differential, and,

(3.g) gm/gal recovery for automobiles used for estimating the mean gm/gal recovery (M_T) will be unrelated to temperature differential.

Algebraically, the above two conditions imply:

(3.h) The expected potential recovery in gm/gal for a given vehicle at a given temperature differential, t, has the form:

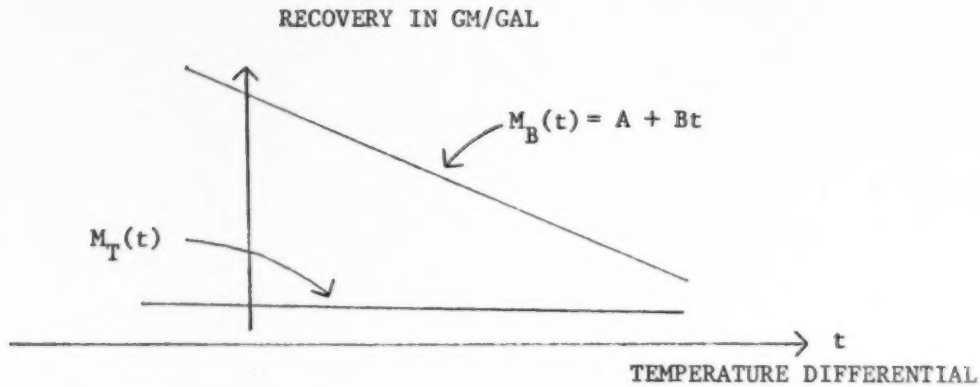
$$M_B(t) = A + Bt,$$

while,

(3.i) The expected actual recovery in gm/gal, $M_T(t)$, has the form:

$$M_T(t) = \text{constant, for any } t.$$

Schematically, the above two assumptions give:



With respect to the actual estimation and statistical assessment of the emission rate, one must estimate the A and B for the potential vapor recovery and the $M_T(t)$ for the actual vapor recovery. In the analysis of the TRW data, ordinary least squares estimation was used and this method will be assumed in what follows.

4.0 Estimation of Emission Rate

Suppose (Y_1,t_1), (Y_2,t_2),.., (Y_{N_B},t_{N_B}) are readings on N_B vehicles to be used for establishing the potential vapor recovery line (baseline), where:

Y_i = gm/gal recovered for the i-th baseline car, $i = 1,2,..,N_B$

t_i = the temperature differential for the i-th baseline car, $i = 1,2,..,N_B$.

Also, suppose that (X_1,τ_1), (X_2,τ_2),..,(X_{N_T},τ_{N_T}) are readings on N_T vehicles denoted as test-cars and,

X_j = gm/gal recovered for the j-th test-car, $j = 1,2,..,N_T$

τ_j = the temperature differential for the j-th test-car.

Then, the emission rate is estimated by:

$$(4.a)\quad \widehat{DE} = \frac{1}{N_T} \sum_{j=1}^{N_T} (\hat{P}(\tau_j) - X_j),$$

where, as before, X_j is the gm/gal reading for the j-th test-car, τ_j is the temperature differential for the j-th test-car and, $\hat{P}(\tau_j) = \hat{A} + \hat{B}\tau_j$, the estimated potential vapor recovery for the j-th car at its temperature differential τ_j. The $\hat{A}$ and $\hat{B}$ are assumed to be the least-squares estimates of A and B in (3.h) and are derived from (Y_1,t_1), (Y_2,t_2),.., (Y_{N_B},t_{N_B}), the N_B baseline cars.

In order to perform a statistical test that the emission rate is within federal regulations one must be able to estimate the standard error (the square root of the variance) of $\widehat{DE}$. That is, insofar as $\widehat{DE}$ would be different if different sets of cars from the population of cars were observed, one must be able to estimate this variability.

Now, with a little algebra it is easy to show that (4.a) reduces to:

$$(4.b.)\quad \widehat{DE} = \hat{A} + \hat{B}\bar{\tau} - \bar{X},$$

where,

$\bar{\tau}$ = the estimated mean temperature differential from the N_T test-cars and,

$\bar{X}$ = the estimated mean gm/gal recovery from the N_T test-cars.

That is, the estimate of emission rate reduces to a comparison between the estimated mean value of returned vapor for the test-cars and the estimated baseline evaluated at the mean temperature differential of the test-cars.

It is a reasonably straight forward task to calculate the variance of $\widehat{DE}$. It is given by:

$$(4.c)\quad \mathrm{Var}(\widehat{DE}) = \mathrm{Var}\,[\hat{A}+\hat{B}\bar{\tau}] + \mathrm{Var}\,[\bar{X}],$$

since the test-cars are assumed to be independent of temperature differential.

But,

$$(4.d)\quad \text{Var}\ (\hat{A}+\hat{B}\bar{\tau}) = \frac{\sigma_B^2}{N_B} + \frac{(\bar{t}-\bar{\tau})^2\sigma_B^2}{(N_B-1)\sigma_t^2}$$

and,

$$(4.e)\quad \text{Var}\ (\bar{X}) = \frac{\sigma_T^2}{N_T}$$

Therefore,

$$(4.f)\quad \text{Var}\ (\widehat{DE}) = \sigma_B^2 \left\{ \frac{1}{N_B} + \frac{(\bar{t}-\bar{\tau})^2}{(N_B-1)\sigma_t^2} \right\} + \frac{\sigma_T^2}{N_T}$$

where,

σ_B^2 = the variance of returned vapor rates (gm/gal) among the baseline cars adjusted for temperature differential,

σ_T^2 = the variance of returned vapor rates (gm/gal) among the test-cars,

σ_t^2 = the temperature differential variance among the baseline cars,

N_B = the number of baseline cars,

N_T = the number of test-cars,

$\bar{t}$ = the mean temperature differential among the baseline cars, and,

$\bar{\tau}$ = the mean temperature differential among the test-cars.

From the statistical analysis of the TRW data (section 7.0 of this report) estimates of the above parameters gave:

$$(4.g)\quad \hat{\sigma}_B^2 = 0.1033$$

$$\hat{\sigma}_T^2 = 2.9116$$

$$\hat{\sigma}_t^2 = 100.6428$$

Hence, it is seen that for any number of baseline cars (N_B) and test-cars (N_T), the estimated emission rate ($\widehat{DE}$) and the variance associated with this estimate may be calculated. However, as can be seen in (4.f), the variance of the estimator is a function of the number of test-cars and baseline cars and the difference between the mean temperature differentials of the test-cars and the baseline cars. In particular, the variance of $\widehat{DE}$ is a decreasing function of N_B and N_T and an increasing function of $(\bar{t}-\bar{\tau})^2$.

The pertinence of the variance formula derived in (4.f) is apparent from the following argument. To wit, since estimates of DE will vary as a function of the number of cars sampled (N_B, N_T), the temperature differential ($\bar{t}$, $\bar{\tau}$) and which cars from the population of cars are sampled, it is important that the estimate, $\widehat{DE}$, be accompanied by a statement which describes the variability of the estimate, or "how close" $\widehat{DE}$ may be to DE. Confidence intervals, which are functions of the standard error of $\widehat{DE}$ (the square root of the variance of $\widehat{DE}$), provide a method of stating how variable is the estimate.

Using a table of normal (0, 1) percentage points one may find the proportion of the time one can expect $\widehat{DE}$ within a certain distance of DE. For example, 95% of the time ($\widehat{DE}$-DE) will be between -1.96 SE($\widehat{DE}$) and 1.96 SE($\widehat{DE}$), giving the inequality:

(4.g) 95% upper and lower confidence limits for DE are:

$$\widehat{DE} - 1.96\ SE(\widehat{DE}) < DE < \widehat{DE} + 1.96\ SE(\widehat{DE}).$$

If 1.96 is replaced by 1.00 then the confidence statement becomes:

(4.h) 68% upper and lower confidence limits for DE are:

$$\widehat{DE} - SE(\widehat{DE}) < DE < \widehat{DE} + SE(\widehat{DE}),$$

which is written, typically, as:

(4.i) $\widehat{DE} \pm SE(\widehat{DE})$.

In general, two sided $100(1-\alpha)$ confidence limits may be written as:

(4.j) $\widehat{DE} \pm Z_{1-\frac{\alpha}{2}} SE(\widehat{DE})$,

where $Z_{1-\frac{\alpha}{2}}$ is the $(1-\frac{\alpha}{2})$-th percentage point of the normal (0, 1) distribution.

In the above argument the concept of "closeness" is defined as the proportion of time $(\widehat{DE}-DE)$ will be between two limits. However, for the problem at hand, consideration need only be given to a lower confidence limit on DE. Specifically, if $Z_{1-\alpha}$ is the $(1-\alpha)$-th percentage point of the normal (0,1) distribution then a lower $100(1-\alpha)$ confidence limit for DE may be written:

(4.k) $DE > \widehat{DE} - Z_{1-\alpha} SE(\widehat{DE})$.

For example, a lower 95% confidence limit may be written as:

(4.l) $DE > \widehat{DE} - 1.64\ SE(\widehat{DE})$,

and, by substituting 1.00 for 1.64 in (4.l) the confidence statement becomes:

(4.m) An 84% lower confidence limit for DE is given by:

$DE > \widehat{DE} - SE(\widehat{DE})$.

The rationale for the use of a lower confidence limit for DE is clear if one examines the two-sided limits given in (4.j). Notice that any decision regarding the compliance of a system to federal regulations must be based only on the lower limit. That is, the system will be deemed out of compliance if and only if the lower limit exceeds .4 gm/gal. In section 5.0 a formal procedure for testing the system's compliance to federal regulations and the properties of that procedure are discussed. Before proceeding to section 5.0,

however, some discussion concerning the factors affecting the standard error of $\widehat{DE}$ is appropriate.

To begin, in Table I the standard error of $\widehat{DE}$ is computed using the estimates in (4.g) calculated from the TRW data. The set of tables gives the estimated standard error of $\widehat{DE}$ as a function of $|\bar{t}-\bar{\tau}|$, N_B and N_T. In particular, Table I gives the estimated standard error of $\widehat{DE}$ at 0, 2, 4, 6 and 8 absolute mean difference temperature differentials for N_T = 80, 100, 150, 200 and 250 test-cars and N_B = 20, 40, 60..., 200 baseline cars.

Inspection of this table shows that the limiting factor in the precision of $\widehat{DE}$ is the number of test-cars. For instance, at a mean difference of 0 in temperature differential the standard error of $\widehat{DE}$ is estimated as:

$$SE(\widehat{DE}) = 0.13093 \text{ for } N_B = 40 \text{ and } N_T = 200.$$

If $SE(\widehat{DE})$ is estimated for 200 baseline cars at an absolute mean difference in temperature differential of 0, the standard errors are:

$$SE(\widehat{DE}) = .19213 \text{ for } N_B = 200 \text{ and } N_T = 80$$
$$= .17214 \text{ for } N_B = 200 \text{ and } N_T = 100$$
$$= .14124 \text{ for } N_B = 200 \text{ and } N_T = 150$$
$$= .12278 \text{ for } N_B = 200 \text{ and } N_T = 200$$
$$= .11029 \text{ for } N_B = 200 \text{ and } N_T = 250$$

Hence, it is seen that the limiting factor in estimating the precision ($SE(\widehat{DE})$) of a balance vapor recovery's differential efficiency is the number of test-cars. It is not the number of cars used in establishing the baseline. The baseline cars appear to behave rather predictably (see section 7.0) while the test-cars show a great deal of car to car variation in their response to the balance system.

An indication of how much more variable the test-cars are than the baseline cars is given by the ratios of the two estimated variances $\hat{\sigma}_T^2$, $\hat{\sigma}_B^2$

given in (4.g), here,

$$\frac{\hat{\sigma}_T^2}{\hat{\sigma}_B^2} = \frac{2.9116}{0.1033} = 28.1$$

which is a large, significant ratio (.01 significance level).

In the next section, discussion is turned toward the use of the estimated standard errors in testing, statistically, a system's compliance to federal regulations.

5.0 A Statistical Test of System Compliance

In section 4.0 methods of estimating the emission rate and the precision of that estimator were given. In this section the use of these estimators in determining a system's compliance to regulations is investigated.

Specifically, the estimated emission rate and its estimated standard error are used to make a decision concerning a system's compliance to federal regulation.

Two mutually exclusive situations present themselves; either the system is in compliance or it is not. Notice that due to the fact that not <u>all</u> cars are tested (from the population of cars to which the regulation applies) and that a sample of cars are used to determine the baseline, one must consider the variability in estimated emission rates if, indeed, different sets of cars had been chosen.

Now, given that one of the two mutually exclusive situations is true, then one of two errors can be made. The first kind of error (Type I error) occurs if, in fact, the system is in compliance but the <u>sample</u> of cars chosen indicates that the system is not. The second kind of error (Type II error) can occur if the system is, in fact, not in compliance but the observed <u>sample</u>

of cars indicates that the system is in compliance.

Customary statistical practice controls the Type I error rate at some fixed level (5%, say) and then, for different emission rates and different sample sizes (numbers of cars N_B, N_T), solves for the Type II error rate.

If $\widehat{DE}$ and $SE(\widehat{DE})$ are the estimated efficiency and estimated standard error then a decision rule of the form:

(5.a) Reject the system if

$$\widehat{DE} > .4 + z_{1-\alpha} SE(\widehat{DE}),$$

where $z_{1-\alpha}$ is the $(1-\alpha)$-th percentage point of the normal (0,1) distribution, has the property that its Type I error rate is α.

For $\alpha = .05$, then $z_{1-\alpha} = 1.64$ and (5.a) can be written:

(5.b) Reject the system if

$$\widehat{DE} > .4 + 1.64\ SE(\widehat{DE}).$$

Now, (5.b) is a decision rule with a 5% Type I error rate.

Suppose, however, that the true system emission rate is greater than .4 (by true it is meant the emission rate in the population). Then, if $\widehat{DE} < .4 + 1.64\ SE(\widehat{DE})$ a Type II error would be made; hence, in order to have a good decision rule, it is required that the probability of a Type II error be small.

If d_1 is the true emission rate in the population and if Pr denotes probability, then:

(5.c) $$\Pr\left\{\widehat{DE} > .4 + 1.64\ SE(\widehat{DE})\right\}$$

$$= \Pr\left\{\frac{\widehat{DE}-d_1}{SE(\widehat{DE})} > \frac{(.4-d_1) + 1.64\ SE(\widehat{DE})}{SE(\widehat{DE})}\right\}$$

$$= 1-\Pr\{\text{Type II Error}\}.$$

Now, $\frac{\widehat{DE}-d_1}{SE(\widehat{DE})}$ has a normal (0, 1) distribution and the probability of rejecting the system, 1-Pr $\{$ Type II Error $\}$, may be calculated for different values of d_1, N_B, N_T and $|\bar{t}-\bar{\tau}|$.

Table II gives this probability for $|\bar{t}-\bar{\tau}| = 0, 4$; $N_B = 20, 40, 80$; $N_T = 80, 150, 250$; and for various values of d_1. Again it is seen that using large numbers of test-cars is more important than using large numbers of baseline cars. For a common d_1, $|\bar{t}-\bar{\tau}|$ and N_T, very little rejection probability is added by adding baseline cars (N_B); however, reasonably large increases in this probability may be achieved by increasing the number of test-cars (N_T) for any number of baseline cars, $|\bar{t}-\bar{\tau}|$ and d_1. Notice that, from the tables, if $d_1 = d_o = .4$ then the probability of rejection is .05, the Type I error rate, which is as it should be.

In the next section discussion is turned to the number of baseline and test-cars required for assessing system compliance.

6.0 Sample Size Determination

In the preceding section some general comments were made with respect to the number of baseline and test-cars needed to assess system compliance. In this section the implications of sample size is discussed.

The first consideration in determining the number of cars required is a substantive one. That is, EPA must decide what levels of emission rate ($d_1 > .4$ gm/gal) must be detected with what probability.

For instance, if one wanted to be at least 90% certain that a system would be found out of compliance if $d_1 = .8$ gm/gal, then one would need in the neighborhood of 250 test-cars and 20 baseline cars (Table II). However, it should be noted that the decision rule given in (5.b) does <u>not</u> require the estimate, $\widehat{DE}$, to be .8 in order to reject the system. In fact, assuming

the same kind of variation is observed when testing is actually performed, (5.b) would give (for a mean difference temperature differential of zero and $N_B = 20$, $N_T = 250$):

Reject the system if:

$$\widehat{DE} > .4 + 1.64\ (.12967) = .612,$$

where $SE(\widehat{DE}) = .12967$ is obtained from Table I.

Hence, it is seen that sample size determination is a statistical calculation after certain substantive decisions are made. However, certain suggestions are not inappropriate. Specifically, the decision rule given in (5.b) assumes that the estimator $\widehat{DE}$ is approximately normally distributed; which is certainly true if each observation which makes up $\widehat{DE}$ is normally distributed. That is, if, for a given t, the distribution of gm/gal is normally distributed. However, even if gm/gal is not a normal variate, $\widehat{DE}$ will be normally distributed if the sample sizes N_B and N_T are reasonably large. Now, insofar as it is suggested that N_T be chosen large relative to N_B, it is also suggested that N_B be chosen to be at least 20 cars, with 40 being preferable. Having more than 40 baseline cars is considered an uneconomic choice because (1) more than 40 cars for the baseline are not considered necessary for normality and, (2) very little additional information is gained concerning the baseline for increases in N_B greater than 40.

As a measure of the gain in information concerning the baseline, a straight line was fitted to the gm/gal recovered and the temperature differential (see section 7.0 on data analysis) for the 14 baseline cars. The following were obtained:

$$(6.2) \qquad \widehat{gm/gal} = \hat{M}_B(t) = \hat{A} + \hat{B}t$$

$$= 3.599 - .0429\ t,$$

and,

$$(6.b) \qquad \text{Variance } (\widehat{gm/gal}) = \sigma_B^2 \left\{ \frac{1}{N_B} + \frac{(t-\bar{t})^2}{(N_B-1)\sigma_t^2} \right\},$$

$$(6.c) \qquad SE(\widehat{gm/gal}) = \sqrt{\text{Variance } (\widehat{gm/gal})},$$

$$(6.d) \qquad CV(\widehat{gm/gal}) = SE(\widehat{gm/gal})/(\widehat{gm/gal}),$$

where, as in (4.g),

$\hat{\sigma}_B^2$ = 0.1033, the estimated gm/gal variance among the baseline cars adjusted for temperature differential,

$\hat{\sigma}_t^2$ = 100.6428, the estimated temperature differential among the baseline cars,

$\bar{t}$ = 5.7857, the mean temperature differential among the baseline cars,

N_B = the number of baseline cars.

Then, for $(t-\bar{t})$ = -8, -6, -4, -2, 0 ..., +8 and N_B = 20, 40, 60, ..., 200, computations gave the predicted potential recovery (6.a); the variance of the predicted value, (6.b); the standard error of the predicted value, (6.c); and the coefficient of variation of the predicted value (6.d). These calculations are presented in Table III.

With respect to Table III, for $(t-\bar{t})$ = 0 it is seen that:

$SE(\widehat{gm/gal})$ = .07189 for N_B = 20

= .05083 for N_B = 40

= .04150 for N_B = 60

= .03594 for N_B = 80

. .

. .

= .02273 for N_B = 200.

Hence, the standard error of the predicted (potential) gm/gal decreases

rather sharply, initially, and then decreases slowly as N_B increases. Again, reasonably good information about the baseline can be obtained with relatively small numbers of cars, with a great many cars needed to increase this information even marginally.

Discussion is now turned to the data analysis techniques used for the estimation of the parameters used in the preceding sections. In addition, several heuristic analyses of the test-car data are considered.

7.0 Data Analysis: Sample Size Development

The data anlaysis performed for the 14 baseline cars and 143 test-cars had several objectives.

First, an examination of the relationship between gm/gal and temperature differential (t) was made. For the baseline cars, this relationship was estimated by an ordinary least squares analysis as:

$$(7.a) \qquad \widehat{gm/gal} = \hat{M}_B(t) = \hat{A} + \hat{B}t$$

$$= 3.599 - .0429\ t,$$

where, t = vehicle tank temperature-dispensed liquid temperature.

The standard errors of $\hat{A}$, $\hat{B}$ and $\hat{M}_B(t)$ were estimated as:

$$(7.b) \qquad SE(\hat{A}) = 0.100$$

$$SE(\hat{B}) = 0.0089$$

$$SE(\hat{M}_B(t)) = \hat{\sigma}_B \sqrt{\frac{1}{N_B} + \frac{(t-\bar{t})^2}{(N_B-1)\hat{\sigma}_t^2}}$$

where,

$\hat{\sigma}_B^2$ = the estimated gm/gal variance among the baseline cars adjusted for temperature differential,

= 0.1034 for these data,

$\hat{\sigma}_t^2$ = the estimated temperature differential variance among the baseline cars,

= 100.642 for these data,

$\bar{t}$ = the estimated mean temperature differential for the baseline cars,

= 5.785 for these data,

N_B = the number of baseline cars,

= 14 for these data.

Further analysis of the baseline cars was not considered due to the small number of cars (14) and due to the fact that a reasonably good fit was achieved; here, the correlation between the observed baseline gm/gal readings and the fitted baseline readings, $\hat{M}_B(t)$, was found to be 0.813. Hence, it was concluded that a linear relationship was adequate to explain the gm/gal recovery and temperature differential relationship for the baseline cars.

Next, attention was turned to the behavior of the test-cars. For these cars, analyses concerning the day to day and station to station variation were performed. The analyses proceeded as follows. For each of the three days of testing within each station, a least squares line was fitted to gm/gal and temperature differential; this resulted in six lines. These six lines, then, were statistically tested in order to determine if any differences existed among the lines between the days (within the stations) and across the stations.

The results of the analysis indicated that there were no differences among the days and that gm/gal and temperature differential are uncorrelated for the test-cars (the basis for assumption (3.h)). However, some difference between the stations was found, with the Standard station giving somewhat greater average recovery than the Gulf station. Here,

(7.c) $\bar{X}_S = 2.71$ and $SE(\bar{X}_S) = \sqrt{\frac{2.8402}{38}} = .27$

$\bar{X}_G = 2.01$ and $SE(\bar{X}_G) = \sqrt{\frac{2.8313}{105}} = .16$

Now, while station to station differences were found, it is not possible, statistically, to determine if the differences were due to the stations, themselves, or to the two different systems used at the stations.

In the calculations made for Tables I, II, all the test-cars were pooled together to estimate their variance. Insofar as there may be some station to station variation, this estimated variance $\hat{\sigma}_T^2$ (see (4.f) and (4.g)) slightly overestimates the variability between test-cars; however, the impact of this slight over-estimation is to make the sample sizes slightly conservative. That is, for a particular station and system, observed standard errors of differential efficiency may be expected to be slightly smaller than given in Table I. Also, the decision rule, for given N_B and N_T in Table II, should have slightly greater rejection probabilities than calculated.

The analysis given above was performed for one very specific objective; namely, to estimate the important parameters necessary for the calculation of sample sizes for assessing system compliance to federal regulations. In the next section more heuristic analyses of the test-car data are performed in order to isolate factors other than temperature differential which may be important in vapor recovery.

8.0 Data Analysis: Exploratory

In this section an attempt is made to examine the gm/gal recovery for the test-cars as a function of several factors. Specifically, by analysis of variance techniques, an attempt to assess the impact of nozzle-fit, station,

time of day, year of manufacture, country of manufacture (foreign or domestic), the number of gallons dispensed, the vapor temperature, the dispensed liquid temperature and vapor volume on gm/gal recovery was attempted. The sum of squares for testing the significance of these factors is given in Table IV.

In Table IV it is seen that only nozzle fit, the stations and temperature differential were found significant. Notice that enough of the between car variation is accounted for by the other factors in the analysis that temperature differential is shown to influence vapor recovery in test-cars.

Now, in order to examine the influence of nozzle-fit on recovery, station differences were suppressed and three parallel lines (by nozzle fit) were fitted to gm/gal recovered and temperature differential. The three lines were estimated as:

(8.a) For nozzle-fit:

$$\text{GOOD} \qquad \widehat{gm/gal} = 3.594 - .0373\ t,$$

$$\text{FAIR} \qquad \widehat{gm/gal} = 2.968 - .0373\ t,$$

$$\text{POOR} \qquad \widehat{gm/gal} = 1.586 - .0373\ t.$$

Now, recalling that for the baseline cars (all of which had GOOD nozzle fits) the baseline was estimated as:

(8.b) $$\text{BASELINE} \quad \widehat{gm/gal} = 3.599 - .0429\ t.$$

It is seen that there appears to be a natural ordering of the system's ability to recover vapors and that ordering is based simply upon the fit achieved between the nozzle and the tank. Therefore, it appears that compliance reduces to achieving a good fit. Now, while this may be obvious from the physical process involved, it is not obvious that certain types of automobiles have greater percentages of poor nozzle-fits.

Proceeding with this exploratory analysis, characteristics of the test-cars were tabulated by nozzle-fit in order to determine if nozzle fit was

associated with any particular car characteristics. Two characteristics were found to be associated with nozzle-fit. They are:

(8.c) The country of manufacture, and,

(8.d) The year of manufacture.

Tabulating the test-cars by these characteristics the following are obtained:

	Year of Manufacture					
	≤ 1969		≥ 1970			
	No.	(%)	No.	(%)	Total	(%)
GOOD	14	(25.0)	38	(43.6)	52	(36.3)
FAIR	9	(16.1)	11	(12.6)	20	(13.9)
POOR	33	(58.9)	38	(43.7)	71	(49.8)
TOTAL	56	(100.0)	87	(100.0)	143	(100.0)

A chi-square test for testing the independence of year of manufacture and nozzle-fit gives $\chi_2^2 = 5.15$ which is significant at the .07 level (93% confidence). An indication that newer cars tend to achieve better nozzle-fits.

For country of manufacture the tabulation provides:

	Domestic		Foreign			
	No.	(%)	No.	(%)	Total	(%)
GOOD	47	(40.2)	5	(19.2)	52	(36.3)
FAIR	18	(15.4)	2	(7.7)	20	(13.9)
POOR	52	(44.4)	19	(73.1)	71	(49.8)
TOTAL	117	(100.0)	26	(100.0)	143	(100.0)

As above, a chi-square test for independence gives: $\chi_2^2 = 6.98$ which is significant at the .03 level (97% confidence), strongly suggesting that foreign cars have a significantly greater percentage of poor fitting nozzles than cars manufactured domestically.

Hence, in concluding this section, it is suggested that the vapor balance

recovery system's ability to remove vapors is predictable by the interface between the nozzle and the vehicle tank and that if a good fit can be achieved then the system will be found in compliance. In addition, it appears that better fits occur with newer cars and domestic cars.

REFERENCES

[1] Hasselmann, D. E., "Test Evaluation of Gasoline Transfer Vapor Recovery Systems," TRW, Inc., Redondo Beach, California, Prepared for: Emission Measurements Branch, Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, North Carolina under Contract No. 68-02-0235.

TABLE I

Standard Errors of $\widehat{DE}$ as a Function

of N_B, N_T and $|\bar{t}-\bar{\tau}|$

$N_B = 20$

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.20387	.18516	.15678	.14045	.12967
2	.20440	.18574	.15746	.14122	.13050
4	.20598	.18748	.15951	.14350	.13296
6	.20859	.19034	.16286	.14721	.13697
8	.21219	.19428	.16745	.15227	.14239

$N_B = 40$

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19743	.17805	.14831	.13093	.11929
2	.19770	.17834	.14866	.13133	.11973
4	.19850	.17923	.14972	.13253	.12104
6	.19982	.18069	.15147	.13450	.12320
8	.20166	.18272	.15388	.13721	.12616

$N_B = 60$

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19524	.17561	.14537	.12760	.11563
2	.19542	.17581	.14561	.12787	.11593
4	.19595	.17640	.14633	.12868	.11682
6	.19684	.17739	.14751	.13003	.11830
8	.19807	.17875	.14916	.13189	.12035

$N_B = 80$

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19413	.17438	.14389	.12590	.11375
2	.19427	.17453	.14407	.12610	.11398
4	.19467	.17498	.14461	.12672	.11466
6	.19533	.17572	.14550	.12774	.11579
8	.19626	.17675	.14675	.12916	.11735

$N_B = 100$

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19347	.17364	.14298	.12487	.11261
2	.19357	.17376	.14313	.12503	.11279
4	.19389	.17411	.14356	.12553	.11334
6	.19443	.17471	.14428	.12635	.11425
8	.19517	.17554	.14529	.12750	.11552

$N_B = 120$

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19302	.17314	.14238	.12418	.11184
2	.19311	.17324	.14250	.12431	.11199
4	.19338	.17354	.14286	.12473	.11245
6	.19382	.17404	.14347	.12542	.11322
8	.19445	.17473	.14431	.12638	.11428

N_B= 140

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19270	.17279	.14195	.12368	.11129
2	.19278	.17287	.14205	.12380	.11142
4	.19301	.17313	.14236	.12416	.11182
6	.19339	.17355	.14288	.12475	.11248
8	.19392	.17415	.14360	.12558	.11339

N_B= 160

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19246	.17252	.14162	.12331	.11087
2	.19253	.17259	.14171	.12341	.11099
4	.19273	.17282	.14199	.12372	.11134
6	.19306	.17319	.14244	.12424	.11192
8	.19353	.17371	.14307	.12497	.11272

N_B= 180

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19228	.17231	.14137	.12301	.11055
2	.19233	.17238	.14145	.12311	.11065
4	.19251	.17258	.14169	.12339	.11096
6	.19281	.17291	.14210	.12385	.11148
8	.19323	.17337	.14266	.12450	.11220

$N_B = 200$

$\lvert\bar{t}-\bar{\tau}\rvert$ \ N_T	80	100	150	200	250
0	.19213	.17214	.14117	.12278	.11029
2	.19218	.17220	.14124	.12286	.11038
4	.19234	.17238	.14146	.12312	.11066
6	.19261	.17268	.14182	.12353	.11113
8	.19298	.17310	.14233	.12412	.11178

TABLE II

Probability of System Rejection as a Function of

d_1, N_B, N_T and $|\bar{t}-\bar{\tau}|$

PROBABILITY OF SYSTEM REJECTION

N_T	N_B	d_1	$\lvert\bar{t}-\bar{\tau}\rvert$	20		40		80	
				0	4	0	4	0	4
80		.40		.050	.050	.050	.050	.050	.050
		.45		.081	.081	.082	.082	.083	.083
		.50		.125	.124	.128	.127	.130	.130
		.55		.182	.180	.189	.188	.192	.192
		.60		.254	.251	.265	.263	.271	.270
		.65		.339	.334	.354	.351	.362	.361
		.70		.433	.427	.452	.448	.462	.460
		.75		.530	.523	.552	.549	.564	.562
		.80		.626	.618	.650	.646	.662	.660
		.85		.714	.707	.738	.734	.751	.749
		.90		.791	.784	.813	.810	.825	.823
		.95		.854	.848	.874	.870	.883	.882
		1.00		.903	.898	.919	.916	.926	.925
		1.05		.939	.935	.950	.948	.956	.955
150		.40		.050	.050	.050	.050	.050	.050
		.45		.093	.092	.096	.095	.098	.097
		.50		.158	.155	.167	.165	.172	.171
		.55		.247	.242	.264	.261	.275	.273
		.60		.357	.349	.385	.380	.401	.398
		.65		.481	.471	.518	.511	.538	.535
		.70		.607	.595	.649	.641	.671	.668
		.75		.723	.710	.764	.757	.785	.782
		.80		.818	.807	.854	.848	.872	.869
		.85		.890	.881	.918	.913	.931	.929
		.90		.939	.932	.958	.955	.966	.965
		.95		.969	.964	.980	.978	.985	.984
		1.00		.985	.983	.991	.991	.994	.993
		1.05		.993	.992	.996	.996	.997	.997
250		.40		.050	.050	.050	.050	.050	.050
		.45		.104	.103	.111	.109	.114	.114
		.50		.192	.187	.211	.207	.223	.221
		.55		.314	.304	.351	.344	.374	.370
		.60		.461	.445	.514	.504	.547	.541
		.65		.613	.594	.675	.664	.711	.705
		.70		.749	.731	.809	.799	.840	.835
		.75		.855	.839	.902	.894	.924	.921
		.80		.925	.914	.956	.952	.969	.967
		.85		.966	.959	.983	.981	.989	.988
		.90		.986	.983	.994	.993	.997	.996
		.95		.995	.993	.998	.998	.999	.999
		1.00		.998	.997	.999	.999	.999	.999
		1.05		.999	.999	.999	.999	.999	.999

TABLE III

Baseline Precision as a Function of N_B and $(t-\bar{t})$

$N_B = 20$

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
$\bar{}8$	3.6943	.00863	.09288	.025142
$\bar{}6$	3.6084	.00711	.08434	.023374
$\bar{}4$	3.5225	.00603	.07767	.022050
$\bar{}2$	3.4366	.00538	.07338	.021351
0	3.3507	.00517	.07189	.021455
2	3.2648	.00538	.07338	.022475
4	3.1790	.00603	.07767	.024433
6	3.0931	.00711	.08434	.027269
8	3.0072	.00863	.09288	.030887

$N_B = 40$

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
$\bar{}8$	3.6943	.00427	.06534	.017687
$\bar{}6$	3.6084	.00353	.05943	.016470
$\bar{}4$	3.5225	.00301	.05482	.015563
$\bar{}2$	3.4366	.00269	.05186	.015090
0	3.3507	.00258	.05083	.015171
2	3.2648	.00269	.05186	.015884
4	3.1790	.00301	.05482	.017245
6	3.0931	.00353	.05943	.019214
8	3.0072	.00427	.06534	.021728

$N_B = 60$

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
$\bar{}8$	3.6943	.00284	.05326	.014417
$\bar{}6$	3.6084	.00235	.04847	.013432
$\bar{}4$	3.5225	.00200	.04473	.012700
$\bar{}2$	3.4366	.00179	.04234	.012319
0	3.3507	.00172	.04150	.012387
2	3.2648	.00179	.04234	.012967
4	3.1790	.00200	.04473	.014072
6	3.0931	.00235	.04847	.015670
8	3.0072	.00284	.05326	.017711

$N_B = 80$

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
$\bar{}8$	3.6943	.00212	.04609	.012475
$\bar{}6$	3.6084	.00176	.04195	.011626
$\bar{}4$	3.5225	.00150	.03873	.010995
$\bar{}2$	3.4366	.00134	.03666	.010668
0	3.3507	.00129	.03594	.010727
2	3.2648	.00134	.03666	.011229
4	3.1790	.00150	.03873	.012183
6	3.0931	.00176	.04195	.013563
8	3.0072	.00212	.04609	.015326

N_B= 100

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIATION
$^{-}8$	3.6943	.00170	.04120	.011153
$^{-}6$	3.6084	.00141	.03751	.010395
$^{-}4$	3.5225	.00120	.03463	.009832
$^{-}2$	3.4366	.00108	.03279	.009541
0	3.3507	.00103	.03215	.009595
2	3.2648	.00108	.03279	.010043
4	3.1790	.00120	.03463	.010895
6	3.0931	.00141	.03751	.012127
8	3.0072	.00170	.04120	.013701

N_B= 120

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIANCE
$^{-}8$	3.6943	.00141	.03760	.010177
$^{-}6$	3.6084	.00117	.03423	.009487
$^{-}4$	3.5225	.00100	.03161	.008975
$^{-}2$	3.4366	.00090	.02993	.008709
0	3.3507	.00086	.02935	.008759
2	3.2648	.00090	.02993	.009168
4	3.1790	.00100	.03161	.009945
6	3.0931	.00117	.03423	.011068
8	3.0072	.00141	.03760	.012503

$N_B = 140$

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIANCE
$\bar{}8$	3.6943	.00121	.03480	.009420
$\bar{}6$	3.6084	.00100	.03169	.008782
$\bar{}4$	3.5225	.00086	.02927	.008308
$\bar{}2$	3.4366	.00077	.02771	.008063
0	3.3507	.00074	.02717	.008109
2	3.2648	.00077	.02771	.008487
4	3.1790	.00086	.02927	.009206
6	3.0931	.00100	.03169	.010246
8	3.0072	.00121	.03480	.011573

$N_B = 160$

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIANCE
$\bar{}8$	3.6943	.00106	.03255	.008810
$\bar{}6$	3.6084	.00088	.02964	.008214
$\bar{}4$	3.5225	.00075	.02737	.007771
$\bar{}2$	3.4366	.00067	.02592	.007542
0	3.3507	.00065	.02542	.007585
2	3.2648	.00067	.02592	.007939
4	3.1790	.00075	.02737	.008611
6	3.0931	.00088	.02964	.009583
8	3.0072	.00106	.03255	.010823

N_B= 180

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIANCE
$^{-}8$	3.6943	.00094	.03068	.008305
$^{-}6$	3.6084	.00078	.02794	.007744
$^{-}4$	3.5225	.00067	.02581	.007326
$^{-}2$	3.4366	.00060	.02444	.007111
0	3.3507	.00057	.02396	.007152
2	3.2648	.00060	.02444	.007485
4	3.1790	.00067	.02581	.008118
6	3.0931	.00078	.02794	.009034
8	3.0072	.00094	.03068	.010203

N_B= 200

$(t-\bar{t})$	PREDICTED VALUE	VARIANCE	STANDARD DEVIATION	COEFFICIENT OF VARIANCE
$^{-}8$	3.6943	.00085	.02910	.007878
$^{-}6$	3.6084	.00070	.02651	.007346
$^{-}4$	3.5225	.00060	.02448	.006950
$^{-}2$	3.4366	.00054	.02318	.006746
0	3.3507	.00052	.02273	.006785
2	3.2648	.00054	.02318	.007101
4	3.1790	.00060	.02448	.007701
6	3.0931	.00070	.02651	.008570
8	3.0072	.00085	.02910	.009678

IV-1

TABLE IV

ANOVA Table for gm/gal: Test Cars

Source of Variation	Degrees of Freedom	Sums of Squares	F-value
Nozzle Fit	2	73.33	16.94 ***
Station (Gulf, Standard)	1	11.47	5.30 *
Time of Day (AM, PM)	1	1.82	0.84
Year of Manufacture	1	0.97	0.45
County of Manufacture	1	0.08	0.03
Number of Gallons Disp.	1	3.82	1.76
Vapor Temperature	1	4.83	2.23
Dispensed Liquid Temp.	1	7.61	3.52
Vapor Volume (1)	1	2.06	0.95
Temperature Differential	1	14.96	6.92 **
Residual Error	131	283.40	

* Significant at the 5% (95% confidence) level

** Significant at the 1% (99% confidence) level

*** Significant at the .01% (99.99 confidence) level

(1) Vapor Volume = ½ (Vapor Volume Before + Vapor Volume After)